Transesterified Pongamia oil for Liquid Insulation Application

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Abstract : Transformers and other high power rated electrical equipments use insulating oil. These insulating oil is used as insulant and coolant in transformers and other such allied equipments. Presently, mineral oils are widely used in transformers and electrical equipments as insulating oils. These mineral oils are derivative from crude petroleum and biodegradable upto 50%. Hence vegetable oils are experimented to be used as alternative to mineral insulating oils. This paper investigates the performance of critical characteristics of crude pongamia oil. This is non-edible oil is extracted from pongamia nseeds. It is a source of sustainable and environment-friendly insulating oil. Crude pongamia oil is processed by transesterification methods to improve the performance properties such as color and appearance, density, viscosity, pour point, water content, acidity and electrical properties for better insulation efficiency. Results indicate that crude pongamia processed by transesterification shows improvement in all properties but decrease in flash and fire point values. Further processed oils are evaluated for rapid thermo-oxidative conditioning to evaluate the oxidation stability of oils for a duration of 48 hours and 96 hours.

***Keywords* — Pongamia oil, Transesterification, Mineral insulating oil , Oxidation stability**

I. Introduction

High power rated electrical equipments such as transformers, switchgears, potential transformers, capacitors and other such equipment in the power system use insulating liquid. The performance of these transformers depend on the working condition of its insulation system. Hence, insulation is the most vital part in the transformer. This insulation system consists of insulating oil and kraft paper. Insulating oil contributes to the overall performance of the transformer [1-3]. In transformer, the energy is lost in the form of heat due to leakages of flux or eddy current which in turn rises the temperature of the windings. So this heat is absorbed by the insulating oil and is transmitted to the cooler outer surface. Insulating oil provides an electrical insulation due to its high dielectric property. Mineral oil serve as a extensive insulating oil in electrical equipment. Mineral oil has excellent electrical and cooling properties [4-5]. However mineral oil has relatively low flash point which constitute for high risk of fire and explosion and less biodegradability [6-7].

From the environmental standpoint, the vegetable oil provide an potential alternative sources to mineral oil [8-10]. It provides better environmental safety, low risk of fire and enhance the insulation life. In this regard, most of the researchers have worked on vegetable oils from rape seeds, sunflower, corn, soybeans, grape seeds, sesame etc [11-14]. Most of the oils are edible in nature and processed by transesterification. Hence the experiments are carried out on crude pongamia oil (CPO) which is non-edible vegetable oil. CPO is abundantly available in southern region of Asia [15-16]. Results indicate that CPO shows better performance with respect to electric strength flash point and fire point. Properties like acidity, dissipation factor, resistivity, density, viscosity pour point and oxidation stability needs modification. Hence the CPO is processed by transesterification (TE-PO) [17-19]. The critical properties are also evaluated on the processed MIO,CPO & TE-PO. During use in the transformer the properties of insulating oil tend to deteriorate mainly due to thermo-oxidation [20-29]. Hence the oils were conditioned for rapid thermo oxidative ageing to evaluate their long term performance.

This paper investigates on the critical characteristics of Pongamia oil as a new insulating oil. The results were compared to performance of mineral insulating oil [16].

II. Procedures AND Experiments

A. Materials

1.0 Samples: The Mineral insulating oil is purchased from M/s Raj Petro Specialties Pvt Ltd. Chennai and base

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or crude PO purchased from Gandhi Krishi Vignana Kendra, Bangalore.

2.0 Chemicals used: methanol, propanol, potassium hydroxide (KOH) n-heptane, toluene,(make : Merck)

3.0 MINERAL INSULATING OIL(MIO)

Mineral oil is a hydrocarbon mixture derived from the intermediate distillate which is obtained by processing the crude petroleum. During the present few decades mineral oil based insulating oils are the most popular insulating liquid because of its abundance, satisfying the properties of an ideal transformer oil. Hence it is used for all types of insulating liquid filled transformers of all power rating and other such electrical apparatus [31].

4.0 Chemical composition

Mineral oil is a transparent, colorless liquid composed mainly of various types of hydrocarbons, comprising of straight chain alkanes, branched alkanes, cyclic paraffins and aromatic hydrocarbons.

There are two principal types of mineral oil used for transformers, produced as a result of different oil refining processes:

Paraffinic oil is derived from crude oil containing substantial quantities of naturally occurring n-paraffin.

Paraffinic oil has a relatively high pour point and may require the inclusion of additives to reduce the pour point.

Naphthenic oil is derived from crude oil containing a very low level (or none) of naturally occurring n-paraffins. Naphthenic oil has a low pour point and requires no additives to reduce the pour point. Naphthenic oil provides better viscosity characteristics and longer life expectancy. Naphthenic oil has more polar characteristics than paraffinic oil.

Transformer oils contain inhibitors which delay the oxidation of oil. These inhibitors might be natural, as occur in uninhibited mineral oils, or synthetic and added, as in inhibited oils.

Uninhibited oils must be free of additives, either natural or synthetic, which are used to improve oxidation stability. This includes but is not limited to 2,6 di-tertiary-butyl phenol, 2,6 ditertiary-butyl paracresol, or metal deactivators such as benzotriazole and its derivatives. However in the US, the IEEE accept that < 0.08% inhibitor can be classified as uninhibited.

Inhibited oils are insulating oils which have been supplemented with either 2,6 ditertiary-butyl. phenol or 2,6 ditertiary-butyl paracresol or any other specified and acceptable oxidation inhibitor. New mineral oils are produced to be in accordance with the IEC 60296. Since mineral oil has been used for such a long time, a large database of information is available to enable interpretation of changes to its characteristics and thus predict the possible malfunction of a transformer. IEC 60422 is a good tool to evaluate the quality of insulating oils in operational transformers.

5.0 CRUDE PONGAMIA OIL(CPO)

Crude Pongamia oil is extracted from the seeds/ pods of Pongamia tree. This species is a plant of Leguminosea family found in Eastern Himalaya, Sri lanka and southern India

Chemical composition of pongamia oil

The seeds of Pongamia oil tree yield an essential oil, It has a high content of triglycerides, and its disagreeable taste and odour are due to bitter flavonoid This combined with variances in soil and weather can change the specific composition of Pongamia oil. Typically Pongamia oil is composed of the following fatty acids.

Fig 1: Pongamia tree

Fig 2: Pods of Pongamia

Fig 3: Pods of Pongamia

Fig 4: Seeds of Pongamia

Table-1 : Typical fatty acid composition of pongamia oil

Percentage	Nomenclature	Fatty acid
3.7% – 7.9%	C16:0	Palmitic
2.4% – 8.9%	C18:0	Stearic
44.5% – 71.3%	C18:1	Oleic
10.8% – 18.3%	C18:2	Linoleic
2.60%	C18:3	Linolenic
2.2% – 4.7%	C20:0	Arachidic
9.5% – 12.4%	C20:1	Eicosenoic
4.2% – 5.3%	C22:0	Behenic
1.1% – 3.5%	C24:0	Lignoceric

Uses: Parts of Pongamia tree is used as tooth brush & in manufacture of soaps. Pongamia oil is not been used for cooking because of its bitter taste and irritable odour.

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Leaves are used as fodder and green manure. Medical use include use of Roots of Pongamia seeds are used in treatment of ulcers and also for cleaning teeth and strengthening gums.(Pong2). The kernel is grinded with black pepper and given malarial fever. Flowers are used in diabetes internally and externally in alopecia. The Pongamia seeds are used with camphor help to check diseases like scabies, eczema, ringworm infestation etc.

The paste of leaves is applied on wounds helps to relieve pain and swelling of the wounds. In chronic sinusitis powder of leaves of karanja plant taken through nose gives relief. Applying mash of pulp of karanja flowers on head helps to check alopecia. Ghee prepared with bark of karanja is useful in diseases like syphilis and gonorrhea.

Pongamia oil is also used on skin to keep away the insects and other microbes from the surface. anti-parasitic, wound healing and analgesic properties The extracts are also used as insecticide and anti microbialial, skin diseases for itching and as antiseptic and antifungal.

The oil mixed with neem, guduchi and arishtak,karanja helps to check skin diseases. Bath with leaves boiled in water is useful in arthritis. Its use is indicated in piles, tumors, worm and wounds. Its use has also been indicated in checking obesity. On the other side the parts of the Pongamia oil is used in treatment of circulatory, respiratory, digestive, urinary disorders.

Transesterification of pongamia oil (TE-PO)

The crude PO does not possess all the required characteristics of an ideal insulating oil. Hence, the PO need to be processed to improve its performance. Two methods have been experimented like transesterification. Transesterification is a process to convert triglycerides to fatty acids methyl esters. Transesterification of PO is carried out by the reaction of PO and methanol (CH_3OH) in the volume ratio of 1:6, with KOH as base catalyst, The process is shown in the flow chart. The process comprises of two stages as referred in fig 5. first is reaction stage and the second conditioning stage is common procedure to remove the residual acids, water soluble, moisture, sediments dissolved moisture and suspended particles. The treatment process shown in figure 5 and the finished products are shown in figure 6.

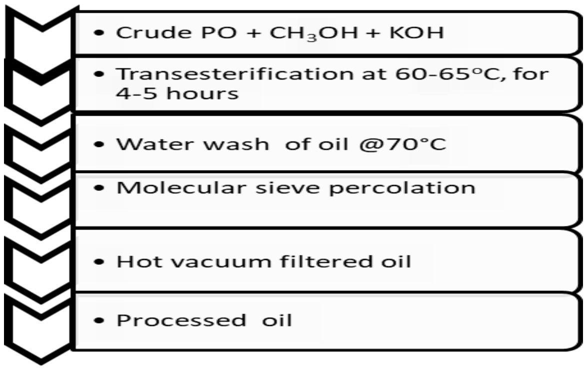

Fig.5 processing of pongamia oil

Fig.6. Samples of mineral oil and pongamia oil

C) The PO is evaluated for the properties listed in the specification standard IEC 62770 [30-32], which takes reference to the sub standards for the test methods as mentioned in the subsequent test methods. Further, the aged samples are tested for physiochemical properties and electrical properties.

1) Breakdown voltage (Electric Strength): Breakdown voltage is measured in accordance with IEC: 60156 using Electric Strength apparatus [33]. The oil sample, contained in a specified container is subjected to an increasing AC electrical field, by means of a constant rate of voltage, until breakdown occurs.

2) Dielectric dissipation factor and dielectric constant: Dielectric Dissipation Factor (DDF) and Dielectric constant (DC) is measured in accordance with IEC:60247 [34] at 100ºC using dissipation factor, dielectric constant, specific resistance equipment,

3) Volume resistivity: Volume resistivity is measured by following the test method mentioned in IEC:60247 [34], by using Dissipation factor, Dielectric constant, Specific Resistance equipment. Measurements were made at 500V DC/2mm

4) Density: Density is measured as per ISO:3675 [35], using hydrometer, by suspending the hydrometer into the oil samples. Hydrometer readings are obtained at convenient

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temperatures with readings of density hydrometer.

5) Kinematic Viscosity: Viscosity is obtained by measuring the time for a fixed volume of liquid to flow under gravity through a calibrated glass capillary Oswald U tube viscometer Constant temperature bath. Viscosity is measured in accordance with ISO:3104 at 40ºC [36].

6) Pour point: pour point is measured according to standard ISO:3106 [37] by using automatic pour point apparatus.

7) Interfacial tension: The interfacial tension is measured in accordance with ASTM D 971[38] by using Interfacial tensiometer.

8) Water content: Water content is measured as per the standard IEC:60814[39] using Karl Fischer Moisture meter by using Karl Fischer Moisture meter.

9) Acidity number: The acidity of insulating oil is measured by the required quantity in milligram of potassium Hydroxide (KOH) to entirely neutralize the acidity of a specific quantity (in gram) of the oil. Acidity is measured by titration as per the standard IEC 62021-1-2007[40].

10) Flash point and fire point: Flash point and fire point is carried out by Cleveland open cup according to standard ISO:2592 [41] by Flash and Fire point apparatus.

11) Oxidation stability conditioning

After the processing treatment the insulating oils viz, MIO, PO,TE-PO are contained for rapid thermo-oxidation reaction at accelerated conditions for 48 hrs at 120ºC with bubbling of oxygen using oxidation stability apparatus, as per the standard IEC 61125 [42].

III. RESULTS AND DISCUSSION

The results obtained for the mineral insulating oil (MIO) and crude pongamia oil is given in table 2. The table also shows the acceptable limits as per the specification standard IEC 62770. The results of crude pongamia oil is compared to that of mineral oil to understand the performance level.

Also the results of crude pongamia oil is compared to the acceptance limits as per the specification standard IEC :62770. Crude pongamia oil (CPO) does meet the specification in density, viscosity, electric strength, flash point and fire point but not for pour point, acidity, dissipation factor. Resistivity value for CPO is very low when compared to that of the mineral oil. Hence the CPO was processed by transesterification. Transesterification process help in recombination of ester molecules by interacting with methane radical. Further the treated oil is washed with hot water to remove the l water soluble such as methane and acids. At this point the acid content of oil is about 2mgKOH/g. After washing the oil is passed through molecular sieve columns to further reduce acids and water content. Repeat the molecular sieve treatment till no change in acidity is observed. Further to reduce the moisture content to below 200 ppm treat the oil with hot vacuum filtrations. Transesterified oil (TE-PO) is measured for the essential parameters. Tranesterified oil is further conditioned for oxidation process to measure the performance of oxidation stability characteristics.The results of oxidized samples are prefixed with OS. The performance for CPO, TE-PO and OS-TE-PO, are compared to the acceptance limits as per IEC 62770 and the performance of MIO.

TABLE 2. Performance of mineral insulating oil and crude pongamia oil

Sl No.	Results of MIO,CPO with acceptance limits as per IEC 62770-2013				
	Characteristics	**Acceptable limits**	**MIO**	**CPO**	**Test Method**
1.	Breakdown voltage , kV @25 ºC	30 (min)	34.7	44.1	IEC : 60156-1995
2.	Dielectric dissipation factor & Dielectric constant @ 90 ºC	0.2 (max)	0.00050 & 2.032	2.76 & 3.41	IEC : 60247-2004
3.	Volume resistivity, *E12, Ohm-cm @ 27 ºC & 90 ºC	Under consideration	3000 & 250	0.048 & 0.0050	IEC : 60247-2004
4.	Density, kg/dm^3 @20 ºC	1.00 (max)	0.823	0.931	ISO : 3675-1992
5.	Kinematic Viscosity, cSt @40 ºC	50 (max)	12.39	47.35	ISO 3104-1994
6.	Interfacial tension, mN/m @40 ºC	Under consideration	43	35	ISO : 6295-1983
7.	Pour point, ºC	-10 (max)	- 21	12	ISO : 3016-1994
8.	Water content, ppm	200 (max)	34	657	IEC : 60814-1997
9.	Acid number, mgKOH/g	0.06 (max)	0.0052	10.84	ASTM D 974 -2012
10.	Flash point and fire point, ºC	250 & 300, (min)	154 & 162	258 & 316	ISO : 2592-2000

1) Breakdown voltage:

Higher value of electric strength indicates the maximum voltage at which the oil will function as an insulator. Higher breakdown voltage indicate the capacity of the oil molecules to withstand electrical stress [18]. Figure 7 indicates the average breakdown voltage obtained for each sample. The electric strength value for mineral oil is 34.7kV. Comparatively, the electric strength of PO is 44.1 kV which is about 20% better when compared to that

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of mineral oil. The breakdown voltage for processed oils are 74.2kV and 88.8kV, this occurs because of the removal moisture during the tranesterification processing hence the processed oil shows better electric strength. The pongamia oil after oxidation is cooled to room temperature in a dedicated chamber to avoid the ingress of atmospheric moisture. Hence the oxidized oil indicates higher electric strength of 93.8 kV. Results of CPO,TE-PO and oxidized PO are meeting acceptable limits [43-45].

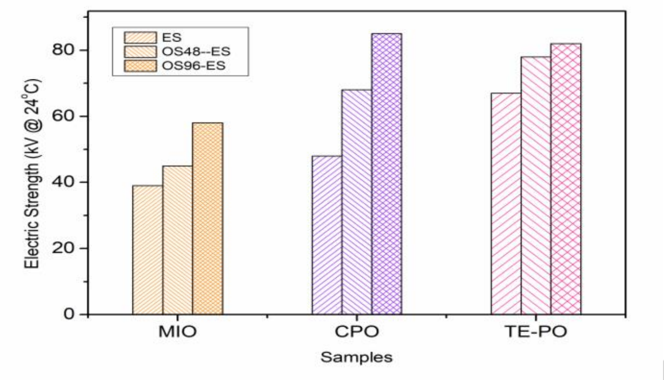

Fig.7.Breakdown voltage of MIO,CPO and TE-PO

2) Dielectric dissipation factor (DDF) and dielectric constant (DC) :

DDF and DC measurements are measured by applying 500V AC at line power frequency of 49.6 Hz. Table 3 shows the values of DDF and DC obtained for The results are shown in table 3.

TABLE 3 DDF AND DC

Sl No	DDF and DC of MO,PO,TE-PO					
	Sample	**DDF @ 90C**	**DC @90°C**	**OS- DDF @90°C**	**OS-DC @90°C**
1.	MIO	0.00050	2.032	0.0011	2.088
2.	CPO	2.76	3.41	6.95	3.21
3.	TE--PO	0.067	3.12	0.49	3.24

Low dissipation factor of oil is desired, as it indicates low power factor. Lower DDF is due to absence of ionic molecules present in the oil [18-19]. DDF of MIO is better than CPO. DDF of CPO is beyond the acceptable limits. CPO after treatment of transesterification, and series of molecular sieve percolation and hot vacuum oil filtered oil (TE-PO), improves DDF by 97% however this is also beyond the permissible limits of IEC 62770. The oxidized oil indicates increased DDF values indicating the deterioration of oil due to the presence of oxidized products [44-45].

3) Resistivity

Resistivity measurement is measured at 500V DC/2mm gap in three terminal cell . Results are shown in table 4.

MIO has high resistivity value compared to CPO, TE-PO. Resistivity values of processed oils indicate improvement, due to the removal of conducting molecules. The resistivity of oxidized oil indicates decreased resistivity due to the presence of oxidized products [19].

TABLE 4 RESISTIVITY

Sl No.	Resistivity x E12, Ohm-cm of MIO , CPO & TE-PO			
	Temp °C	MIO	CPO	TE-PO
1.	27	3000	0.048	0.532
2.	90	250	0.0050	0.056
	Temp °C	OS-MIO	OS-CPO	OS-TE-PO
3.	27	45	0.0050	0.067
4.	90	4.78	5.19E-4	0.0068

After oxidation MIO has decrease of 98% for both temperatures ie 27 and 90°C. Whereas CPO has decreased by 88% and TE-PO, has decreased by 87%. This indicates that pongamia oil has better stability compared mineral oil.

4) Density

Density of mineral oil is 0.823g/cc. The density of crude pongamia oil is 0.931g/cc which is higher than mineral oil. density of PO depends on the molecular weight of the fatty acids. The values obtained are indicated in figure 8.

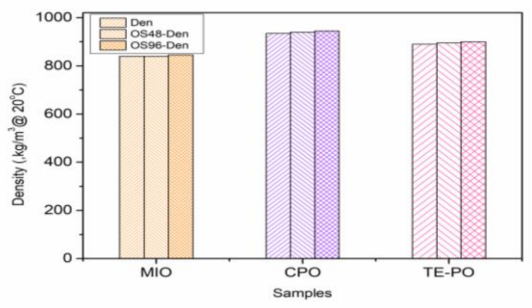

Fig.8.Density of MIO,CPO and TE-PO

Results indicates decrease of density value for TE-PO compared to the CPO. This is due to breakdown of long chain molecules and recombination of ester molecules which is in turn due to the effect of high temperature reaction with methanol solvent and KOH catalyst. Values of CPO,TE-PO is within the acceptable limits. Density of transesterified oil decreases due to the influence of solvent.

5) Kinematic Viscosity(KV)

Viscosity of the insulating oil is very critical property from transformer cooling perspective. Viscosities reading are showed in figure 9.

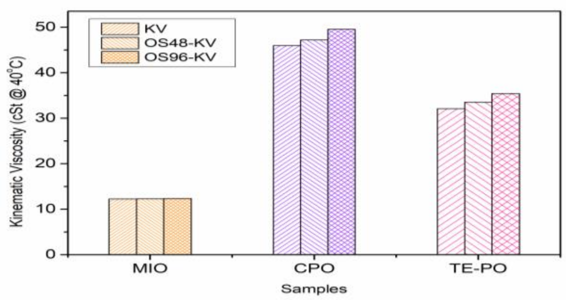

Fig.9.Kinematic viscosity of MIO,CPO and TE-PO

 DOI : 10.18231/2454-9150.2018.1134

Lower viscosity is preferred in case of insulating liquid for better cooling capability of transformer oil. Viscosity of CPO is more compared to that of mineral insulating oil MIO, however it is with the acceptable limits. The higher viscosity value depends on the length of the fatty acids and the combination of cluster of glycerol molecule. Transesterified oil TE-PO decreases viscosity due to breakdown of long chain molecules. Results indicate increase in viscosity of oxidized oil due to the formation of oxidized products.

6) Pour point

Pour point of the MIO records to -24ºC, whereas the pour point of CPO is 12ºC. Pour point readings are shown in figure 10. Esterified oil has low pour point of -6ºC due to the influence of solvent as methanol solvent has very low pour point of -60ºC.

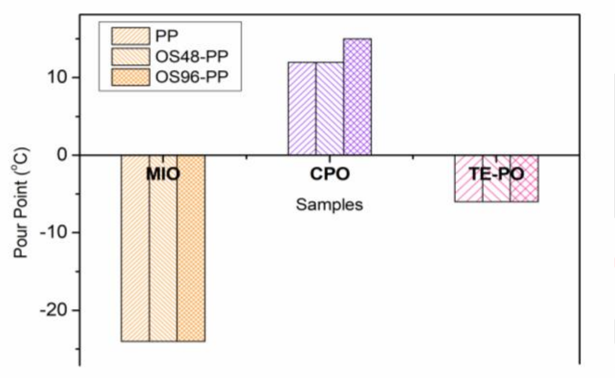

Fig.10.Pour point of MIO,CPO and TE-PO

7) Interfacial tension

Higher value of interfacial tension indicates the absence of polar components. Interfacial tension for MIO, CPO and TE-PO, is given in figure 11.

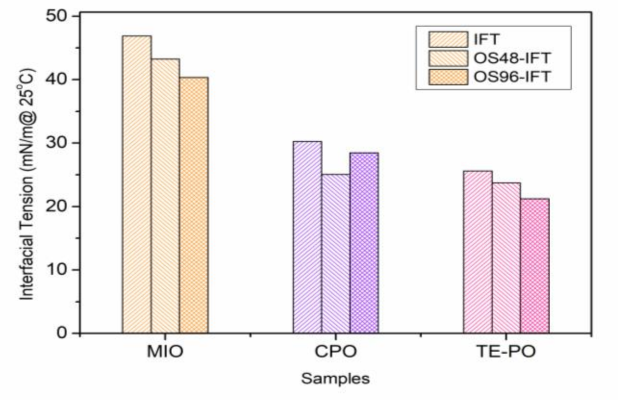

Fig.11. Interfacial tension of MIO,CPO and TE-PO

IFT of MIO is 43 mN/m. Comparatively for CPO the characteristics indicates the value of 35 mN/m. Esterified oil decreases interfacial tension due to influence of solvent. IFT of the TE-PO increased due to increase in polar compounds during oxidation process[46].

8) Water content

Low water content of MIO is necessary to achieve adequate electrical strength and low dissipation losses. Water content results are showed in the figure 12.

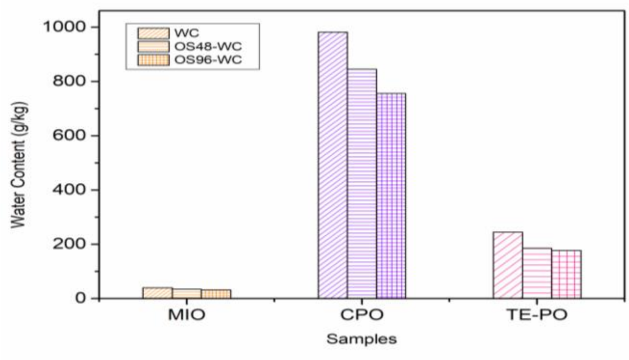

Fig.12.Water Content of MIO,CPO and TE-PO

Water content for a unprocessed CPO is much more than mineral oil. Water content is less in processed oils due to evaporation of water content at elevated temperature and prolonged vacuum filtration for both the processing methods. By vacuum filtration the water content reduces to 400-300 ppm Further on molecular sieve conditioning moisture content is further reduced to 100-200 ppm. Water content is reduced for oxidized oil. This is due to the high temperature conditioning of 120ºC.

9) Acidity

Acidic behavior of aqueous any liquids is indicated on the pH scale. Acidic nature of organic liquid is represented by amount of basic substance required to neutralize when the oil is diluted in a solvent mixture. Hence acidity is one of the important characteristics of liquids. Acids are the aging by-products of oil in transformers and acids can accelerate the aging process. In mineral oil, acidity increases due to thermal and oxidation stresses. The acidity variations are shown in table 5.

TABLE 5: ACIDITY

Sl No.	Acidity of MO,PO,TE-PO		
	Sample	Acidity	OS-Acidity
1.	MIO	0.0052	0.020
2.	CPO	10.84	25.48
3.	TE-PO	0.36	0.56

As the acidity increases the color of the oil also changes due to the presence of oxidized products such as ketones, aldehydes etc. Acidity of CPO is 10.84 mgKOH/g. TE-PO indicates 0.36 mgKOH/g. The acid number of oxidized CPO increases significantly to 25.48 for oxidized oil. Acidity values for CPO,TE-PO is more than acceptable limits.

10) Flash point and fire point

The flash and fire point of CPO is much higher compared to mineral oil. Figure 13 shows that CPO can withstand higher temperature up to more than 300ºC.

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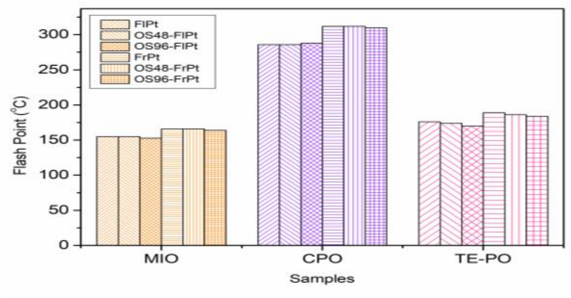

Fig.13.Flash point and Fire point of MIO,CPO and TE-PO

This is due to the bending of the molecular alignment of the fatty acids. Hence pongamia oil can be regarded as fire retardant insulating oil. TE-PO decreases the flash point and fire point compared to the initial performance. Also the temperature difference between flash and fire point is lowered. After oxidation the values of flash point and fire point has marginal decrease.

IV. Conclusion

Crude pongamia oil shows better performance with regard to flash and fire point, electric strength values when compared to mineral oil and very poor performance with respect to acidity, dielectric dissipation factor, resistivity characteristics. Qualities of pongamia oil can be improved by adopting physic-chemical treatment process. The treated oil has shown improvements with respect to all parameter but decreases of flash point and fire point also the temperature difference between flash point and fire point is decreased. The performance of electrical properties is improved by both processing methods. Performance of oxidized oil shows deteriorated values. The processing methods are however needs further improvements or by alternative methods to meet the requirements of IEC 62770.

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